Blockchain Technology for Tracking and Tracing in Supply Chains: A Critical Viewpoint

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Abstract

Tracking and tracing (TnT) in supply chains (SCs) is often mentioned as a very promising area of application for blockchains. At the same time, there is also much reticence and even disillusionment in practice. In this context, we present a literature meta-review and discuss the advantages and disadvantages of using blockchains in SCs.

We find that public permissionless blockchains offer new functionalities (e.g. pseudonymity), which however are often not desired. Moreover, a blockchain loses value in the context of SCs because there is a physical level (goods) in addition to the digital level (information) and these two levels do not necessarily match.

Furthermore, we present a survey of TnT solution providers, which indicates that there are complexity and collaboration problems in supply chains that even a blockchain cannot alleviate. Nevertheless, the surveyed experts generally have a positive attitude towards the blockchain and are willing to give it a chance.

1. Introduction

The use of blockchains in supply chains (SCs) is commonly predicted to have a bright future. In particular, the consulting companies are often naturally optimistic. For example, the "Global Blockchain Leader" at *Deloitte Consulting* states that ([1], p. 1): "Supply chains across industries and countries will be reimagined, improved and disrupted by blockchain technologies." *Accenture* puts blockchains on the same level as ERP systems, fast Internet and industrial automation ([2], p. 1).

Furthermore, there are statements in the scientific literature that support this view: "[…] blockchain as a technology has potential to disrupt many other domains of organisation, including the supply-chain. […] it starts to impact upon the way organisations are governed, supply chain relationships are structured and transactions are conducted" ([3], p. 1) and "[…] we are still in the early stages of unlocking the true potential of blockchain technology in global supply chains, and logistics and transport operations. While there is still some hype […], the future for this technology looks promising" ([4], p. 2063).

However, there are also more cautious voices ([5], p. 16): "Companies and their existing enterprise vendors may prefer to extend the capabilities of their current systems rather than develop blockchain-based solutions." In addition, many experts in practice are reserved and skeptical about blockchains. The reason for this could be a natural hesitation, since the technology is still new and the experts do not yet fully understand it ([6], pp. 230f.). However, the same experts also directly question what benefits a blockchain truly has for their industry. The fact of the matter is that SC blockchains have not reached widespread diffusion ([3], p. 1; [5], p. 13).

It can be argued that blockchain technology is still in its infancy and that it only takes time to develop the right supply chain applications. However, blockchains have existed for more than 12 years, and the first SC blockchain pilot applications were already developed, tested and declared successful in 2016 and 2017 (e.g., *Maersk*, *Walmart* and *MediLedger*, and the other references in [11], p. 11861). The question therefore arises as to whether it truly only takes time or whether SC blockchains simply cannot deliver the widespread positive results that are often predicted.

By far the most popular application of the blockchain in SCs seems to be pilot projects for the tracking and tracing (TnT) of physical goods along the supply chain ([7], [5]). An example is the journey of a mango from the farm to the end-customer at the supermarket. However, efforts to make the supply chain more visible through tracking and tracing have been undertaken for a long time. The literature on these long-standing efforts emphasizes that cooperation between companies in a supply chain is often difficult and that companies are reluctant to share their data

URI: https://hdl.handle.net/10125/71298
978-0-9981331-4-0

([8], p. 350). This problem exists both in a centralized database structure and in a blockchain database [9]. The problem is more about who stores the data and who can access the data, not so much how the data is stored. To solve this problem, the use of a *data trustee* is often considered in the existing literature. A *data trustee* is an independent company that stores the TnT data of different companies (similar to an escrow agent) until a legitimate need for an audit arises ([8], p. 350). This is exactly the opposite of a blockchain.

Based on these cautious viewpoints we ask the following research question, which guides this article: ► *Do blockchains offer new functionality for tracking and tracing in supply chains, and can blockchains solve the problems that have historically hindered comprehensive tracking and tracing across multiple companies?*

The following paper is structured as follows: First, we discuss the technical characteristics and functionality of blockchains, especially with regard to their use in SCs and tracking and tracing in particular. To remove ourselves as much as possible from the research process, we base this discussion largely on review articles concerning the use of blockchains in SCs. We present a meta-review of review articles that are based either on scientific literature and/or on practical case studies (pilot projects) as we aim to incorporate both theoretical and practical perspectives. Based on the identified characteristics and functionality of blockchains, we will discuss to what extent other database technologies have the same functionality.

We conclude with a market analysis of tracking and tracing software vendors. This market analysis will show to what extent TnT solution providers already use blockchains. Furthermore, we present the results of an expert survey among these TnT solution providers (n = 21). In this survey, experts of the solution providers gave their opinion on whether and, if so, why blockchains will change their industry. Emphasis is also placed on potential problems that generally hinder the implementation of tracking and tracing.

The blockchain is currently the subject of much debate. This article aims to provide a good basis for practitioners and for further research regarding the use of blockchains in SCs and tracking and tracing in particular. To the best of our knowledge, this article presents the first systematic meta-review concerning the use of blockchains in the context of SCs. Furthermore, to the best of our knowledge, a market analysis of tracking and tracing software vendors and an expert survey from their viewpoint have not yet been conducted.

2. A meta-review on the use of blockchains in supply chains

Research Context: The functionality of a blockchain is as follows [10]. The blockchain is first and foremost a database in which data is stored in blocks that are cryptographically linked. There are several participants and each participant holds an identical copy of the blockchain (*distributed peer-to-peer ledger*). Generally, a blockchain can be either public permissionless, public permissioned or private permissioned. A public permissionless blockchain is open to everyone, which means that everyone can create an infinite number of accounts and can read, submit and validate data. A public permissioned blockchain is also open to everyone, and everyone can read and submit data, but only selected authorized accounts can verify data. Public blockchains can be largely anonymous (i.e. pseudonymous) since a fixed identification number per account is sufficient. In a private permissioned blockchain, read/write access is restricted. Only authorized accounts may access the blockchain and the individual authorizations (read/write/verify) can be controlled granularly. In a private blockchain, admin organizations often know the true identity of the other participants.

The data in the blocks of a blockchain (e.g., transactions) can be changed, i.e., added, removed or modified, only if a certain number of participants accept the change. It is assumed that the participants are in agreement that no retroactive changes can be made to a blockchain. Only new data can be added, i.e., immutability of the previous blockchain. In addition to the local copy of the blockchain, there is some software that coordinates the various participants via the internet and uses the local copy and rules to decide whether to accept a new data record, i.e., to append a block or not.

The most prominent example of a blockchain is the cryptocurrency *Bitcoin*. *Bitcoin* is a public permissionless blockchain in which the participants are pseudonymous. The *proof of work* algorithm combined with a large number of *miners* ensures that it is hard or at least very costly to reverse or change transactions in the *Bitcoin* blockchain. Every participant can view all past *Bitcoin* transactions, so it can be easily determined whether a participant has enough credit to make a transfer. The combination of these individual components means that a central bank (intermediary) is no longer required.

Because several different forms of a blockchain exist and there is not one definitive blockchain design, it is expedient to clarify by means of a meta-review what is commonly meant by an SC blockchain (e.g., a public permissionless blockchain or a (private) permissioned blockchain).

Identification of research, selection of studies and quality assessment: To identify the review articles we opted for a broad literature search using the search engine *Google Scholar*. Restricting the literature search to certain journals is difficult, since articles about this topic are published in SCM and logistics journals as well as in information systems and computer science journals. A similar approach using *Google Scholar* can be found in [5] and [11].

Given the critical premise of this article, however, it is expedient to restrict the literature search to highly ranked journal articles in order to create a reliable knowledge base. We therefore checked every search result and included the article only if it was published in a journal ranked in the top two quartiles of the *Scimago Journal Rank* in 2018 in at least one category.

Reflecting our broad literature search approach, we intentionally did not include the words “review” or “overview” in the search queries. Instead, we searched the titles of the articles using very generic search terms such as “blockchain supply chain” or “blockchain logistics”. Overall, we checked 42 search queries in February and March 2020, which yielded a total of 828 search results (including duplicates). To increase reliability, two persons conducted the search independently. At the end of the search, they discussed their findings and came to a consensus on which articles to include in the meta-review.

After eliminating duplicates and articles not published in reputable journals, 116 articles remained. Depending on the person, we excluded 40 or 51 of these based on the title of the article and another 54 or 34 articles were eliminated after reading the abstract. For 22 or 31 articles we checked the full text which eventually led to the final number of 12 relevant review articles. Generally, we searched for papers that included a structured literature review and/or a survey of pilot projects. Some articles were review articles but concerned only a specific industry or topic (e.g., agriculture). We excluded these articles and instead focused only on articles with general reviews. This could be a small limitation to the validity of our findings as blockchain technology may be very well suited for a specific industry, that might not be adequately represented in our review. We decided to include a review that focuses on track-and-trace ([5]) and two reviews that focus on trade ([12], [13]), as both topics are relevant for many industries. Table 1 lists the 12 review articles, which serve as the basis for the subsequent analysis.

Results (Data extraction, synthesis and reporting): Table 2 contains three meta-reviews based on the identified articles. The following remarks are directly derived from the references mentioned in Table 2.

1.) We analyzed which technical characteristics the SC blockchain has according to the reviews. Most of the reviews (9/12) define the SC blockchain as a distributed data structure in the form of a linearly linked event log, which uses data blocks that cannot be changed once appended to the blockchain. Many of the review articles also discuss the difference between a public permissionless and a (private) permissioned blockchain. An SC blockchain can be either type. However, five of the reviews state that a private permissioned blockchain is often better suited for a supply chain context (e.g. [11], p. 11863). Three reviews provide more technical detail and explain that computer intensive algorithms such as *proof of work* are often unnecessary and undesirably slow in a permissioned blockchain.

2.) Furthermore, we analyzed which positive themes regarding the blockchain are often mentioned in the different reviews. However, it must be noted that while most articles discuss the following themes from a positive angle, some articles also present a more differentiated viewpoint.

The two most often discussed topics are the use of blockchains in track-and-trace (12/12) and the increased trust due to the use of blockchains (12/12). Both can be linked to the combination of the distributed design of the blockchain and the immutability of its data. If the data is immutable, every historic data input can be checked. Moreover, if every supply chain participant has an identical copy of the blockchain, the immutability of the data is guaranteed through a system of mutual supervision. Furthermore, if the data is captured through Internet of Things (IoT) technology, the data should also have high quality (9/12). Both these features of a blockchain and the integration of IoT technology should increase trust. They should also increase the auditability and validity

Table 1. Identified review articles on the use of blockchains in supply chains

Article	Focus on
Kshetri 2018 [14]	Pilot projects
Wang et al. 2019 [3]	Literature and pilot projects
Hald/Kinra 2019 [15]	Literature
Pournader et al. 2019 [4]	Literature
Queiroz et al. 2019 [16]	Literature
Azzi et al. 2019 [17]	Literature and pilot projects
Hastig/Sodhi 2019 [5]	Literature
Juma et al. 2019 [12]	Literature
Gurtu/Johny 2019 [18]	Literature
Gonczol et al. 2020 [11]	Pilot projects and literature
Chang et al. 2020 [13]	Pilot projects
Tönnissen/ Teuteberg 2020 [19]	Pilot projects and literature

of the data in a blockchain, as discussed in several review articles (9/12). The distributed design of the system also has positive effects regarding its robustness against accidental data loss or cyber-attacks (10/12).

Another often-discussed topic is the possible disintermediation due to the use of blockchains (8/12). However, there is disagreement about whether a blockchain leads to disintermediation in SCs. Tönnissen and Teuteberg (2020) [19], who explicitly researched this topic, reported that based on their sample of SC blockchain projects, there is no disintermediation. Many physical processes in a supply chain cannot be eliminated using a blockchain or any other database. A wholesaler, for example, is a typical intermediary in a supply chain. The role of a wholesaler is to maximize supply chain efficiency through inventory holding and fast logistics. These functions are not eliminated when using a blockchain. In addition, from a technical viewpoint, a permissioned blockchain that is often used in the context of SCs prohibits complete disintermediation even in the digital layer itself.

Many authors also discuss smart contracts (9/12). Smart contracts are automatically triggered if the data in the blockchain matches some predefined criteria. They are best suited for assets that can be traded digitally, such as money or shares. Smart contracts can be useful; however, it is not yet clear how enforceable they are (legally and actually, e.g., [4], p. 2064). Additionally, there is an increased risk due to the automatic triggering of the smart contract (e.g., [15], p. 389).

3.) Finally, we analyzed which problems the authors discuss with regard to blockchains in SCs. In the introduction of this article, we quoted a source ([8]) indicating that many companies are unwilling to share their data. These experiences were learned from longstanding track-and-trace efforts, which, however, did not use a blockchain. Can this problem be solved with blockchains? Five of the review articles were cautious. The data in a blockchain may be stored in a different form compared to that in traditional databases. However, companies are generally hesitant to share sensitive data or even trade secrets, independent of what database technology is used (e.g., [15], p. 389). If the companies in the supply chain, nevertheless, are willing to share their data, they have to integrate their IT systems with the blockchain. Many of the review articles see this as a costly obstacle (8/12). Independent of the blockchain, IT interfaces are generally known to be notoriously costly mainly due to the long-term lifecycle maintenance costs.

Another more technical critique concerns the inferior performance of the blockchain database structure. Many review articles discuss that the current speed of public blockchains is far too slow for most applications (8/12). However, a permissioned blockchain can be much faster (e.g., [3], p. 14).

More conceptually, several of the review articles

Table 2. Characteristics of a supply chain blockchain and recurring topics in the review articles

Characteristic/topic	Discussed in
Technical characteristics of the typical SC blockchain:	
The SC blockchain is a distributed data structure	[14], [3], [15], [4], [16], [17], [5], [12], [11], [19], [13], [18]
The SC blockchain is an event log w. linearly linked data blocks	[3], [15], [4], [16], [17], [5], [12], [11], [19]
The SC blockchain has immutable data	[14], [3], [15], [4], [16], [17], [5], [12], [11], [19], [13], [18]
The SC blockchain is often private and permissioned	[14], [3], [12], [11], [19]
Permissioned SC blockchains often have no *proof of work* (or similar) mechanism	[3], [17], [12]
Recurring topics in the articles (mostly from a positive point of view):	
Track-and-trace	[14], [3], [15], [4], [16], [17], [5], [12], [11], [19], [13], [18]
Combination of blockchain and Internet of Things	[14], [3], [4], [16], [17], [12], [11], [13], [18]
Auditable data and validity of data	[14], [3], [15], [4], [16], [5], [12], [13], [18]
Smart contracts and automation	[14], [3], [15], [4], [16], [17], [12], [13], [18]
Disintermediation	[3], [15], [4], [16], [11], [19], [13], [18]
Trust	[14], [3], [15], [4], [16], [17], [5], [12], [11], [19], [13], [18]
Data robustness/security through decentralized data storage	[14], [3], [15], [4], [16], [17], [12], [11], [13], [18]
Recurring critical points about the blockchain, especially regarding its use in the supply chain:	
Difficult to bring parties together and to integrate technology	[14], [3], [4], [5], [12], [11], [19], [13]
SC parties do not want full transparency	[3], [15], [5], [11], [19]
Performance problems	[3], [4], [17], [5], [12], [11], [13], [18]
Discrepancy between digital and real world	[14], [3], [17], [5], [11], [13]

point out that an SC blockchain does not always have to contain the truth (6/12). As with any database, the *garbage in*, *garbage out* principle holds. The truth in a supply chain takes place in the real physical world and does not have to match what is stored in the digital blockchain (e.g., [5], p. 13).

3. A critical discussion of SC blockchains

The preceding descriptions of the SC blockchain were based on the identified reviews. In the following, we refer to various points from the review articles and enrich them with our own arguments.

Private vs. public blockchains: As mentioned, instead of a public permissionless blockchain such as *Bitcoin*, which has a costly calculation-intensive consensus mechanism, such as *proof of work*, private permissioned blockchains are preferable for an SC context. This means that only the companies involved in the respective supply chain processes may access the SC blockchain, since it is unnecessary to open the blockchain for other participants. However, this eliminates the advantage of a public permissionless blockchain, which does not require a central intermediary, since one or more central organizations must exist (at least for access control).

A second aspect of a public permissionless blockchain, which is eliminated when using a private SC blockchain, is the high degree of anonymity (i.e. pseudonymity). In fact, anonymity is often simply undesirable in a supply chain context. For example, if a supermarket chain wants to trace the origin of a product, the chain must be aware of all actors in the SC blockchain for this product.

A third difference between a public blockchain and a private SC blockchain is that in an SC blockchain, it may be undesirable that all participants can see all information. In the above example of the supermarket chain, the producer of the product certainly has no interest, for example, in allowing a raw material supplier to know from which other suppliers the producer also purchases raw material. The data records within the blockchain must therefore be encrypted or compartmentalized, and an authorization system determines which participant receives the keys to which data records. However, some fundamental problems concerning trade secrets remain. If a supermarket chain can track every ingredient in a product, it would know not only which companies have which suppliers but also roughly how much is purchased from which supplier. In addition, the bill of material or formulation of a product would become transparent. This is a major problem because this information is often a closely guarded trade secret, and neither blockchains nor any other technology can solve this problem.

Two properties apply to both a public permissionless blockchain and an SC blockchain. One is the immutability of the existing data, and the other is the database structure itself. In a blockchain, all data records are connected as blocks, and the existing blocks cannot be changed; only new blocks can be appended to the end. The data structure of a blockchain is similar to the well-known data structure called *Linked list*, with an additional condition that data may only be appended. Such a data structure is normally not used for all data in a database because it is inefficient. In the case of the *Bitcoin* blockchain, this data structure is necessary for the safety precautions to work. In the case of an SC blockchain, which often does not have and does not need these security measures, one could choose another, better-performing database structure.

Comparing blockchains with other more established technologies: Does a blockchain offer new functionality in an SC context or not? A central part of the blockchain mechanism is its distributed database structure with complete replication. This enables mutual supervision by participants and ensures the immutability of the data. A distributed database structure is an old concept that has existed for many decades. The concept of a fully replicating distributed database system is also already more than 30 years old. The challenge in a distributed and fully replicating design is that each node in the network (the firm in our context) has to have the same data and has to agree if data is to be changed. There needs to be some consensus mechanism that ensures that existing data is changed in an orderly manner.

The most famous consensus mechanism for this problem was introduced in 1989/1990 and is called the *Paxos protocol* [20]. The *Paxos protocol* determines whether a firm 'A' receives the key to alter certain data. The other firms have to accept and confirm that firm 'A' receives and has the key. Only then will the other firms accept any change to the specified data made by firm 'A'. It is now easy to imagine how this protocol can be used to prevent the modification of existing data records. However, the standard *Paxos protocol* has a weakness, which can be eliminated by using blockchains. The *Bitcoin* blockchain for example, as a currency, needs to be *byzantine fault tolerant (BFT)* against an attack from nodes that are intentionally malicious. This is difficult to achieve because it is open and pseudonymous, and everyone can verify transactions (it is public and permissionless). Please note that a malicious actor is free to create as many nodes as he or she wants. This is the reason why in the *Bitcoin* blockchain, there is a cryptographic safety measure, the *proof of work* mechanism, which requires a laborious search for the *NONCE* number. This mechanism ensures that one CPU = one vote, instead of one node = one vote. The *Paxos protocol* can also be *byzantine fault tolerant*, but only if there is a fixed number of nodes. A public permissionless blockchain therefore provides new functionality compared to that of older consensus mechanisms such as the *Paxos protocol*.

Hypothetically, situations could exist in which the participants in an SC blockchain are pseudonymous and everyone has read/write/verify access to the SC blockchain. In these situations, a public permissionless blockchain could be the only viable technology. It is, however, an educated guess that these situations are very rare in a supply chain context. Instead, many experts assume that SC blockchains will mostly be private permissioned blockchains, which have a much smaller, fixed number of known participants (see Table 2). Therefore, one could simply use the *Paxos protocol* instead of a blockchain. Thus, in summary, with regard to the research question of this paper, we can state that it is indeed very likely that compared with more established technologies, blockchains do not offer added value for most applications in a supply chain context.

The blockchain as a trending topic: A much-acclaimed success story is a pilot project by IBM and Walmart in which the origin of mangos is recorded using a private permissioned blockchain. In particular, it is stated that blockchain-based tracking and tracing made it possible to track a shipment of mangos within 2.2 seconds, which previously took up to 7 days. The official case report provides the following additional information. Before the blockchain solution the “team started calling and emailing distributors and suppliers, and eventually had an answer almost seven days later” ([21], p. 4f.).

Thus, before the pilot project, there was no database in which all information was stored and no tracking and tracing system existed.

The case report further explains: “We worked with GS1 (the standards authority in barcodes and labeling) to define the data attributes for upload to the blockchain. […] Suppliers used new labels and uploaded their data through a web-based interface.”

The “blockchain” solution in this pilot project therefore means that producers and intermediaries upload barcode-like information into a database.

It could be argued that the success of the pilot did not depend on the use of a blockchain. Instead, the real achievement is probably that Walmart has managed to convince its partners to use other labels and to upload the label information into a database. Generally, it could very well be that companies just needed such a trending topic to refresh their tracking and tracing efforts, irrespective of whether a blockchain or a different technology such as the *Paxos protocol* is used. However, the examined reviews as well as the older literature on earlier TnT projects provide arguments for why these efforts could nevertheless often come up short.

Current limitations: One of the most often touted advantages of a blockchain is the supposedly increased confidence in data quality and auditability. This may be true for a self-contained system such as the *Bitcoin* blockchain. A transaction in the *Bitcoin* blockchain is the reality as *Bitcoins* are completely digital and because they only exist in the blockchain. *Bitcoin* credits exist only through the history of the blockchain. In a supply chain context, however, the positive effect is less pronounced. The physical supply chain does not exist in the digital blockchain that tries to capture the physical supply chain. The data stored in a blockchain does not necessarily correspond to reality in the physical supply chain (see Figure 1). Therefore, the quality of the data in the SC blockchain is only as good as the participants want it to be. The SC blockchain is not a single point of truth; it is only a single point of information.

This difference also affects smart contracts. An SC blockchain in combination with smart contracts and an external escrow account can be used as an automated escrow mechanism. For example, a buyer pays 100 USD into the external escrow account and receives 100 SC coins. A supplier could then for example demand that the buyer reserves 100 SC coins within a smart contract. The 100 SC coins are untouchable until the buyer confirms that he or she has received the goods. The smart contract is then automatically triggered, and the supplier receives the 100 SC coins, which he or she then can exchange back into USD using the external escrow account. The problem, however, is the confirmation that an event has actually occurred. What if the supplier sends the goods and the buyer receives them but simply lies? The truck driver who transported the goods probably cannot solve the dispute either because he or she often has no idea what is inside the boxes. IoT technology can be helpful because automated sensors are more difficult to manipulate, but also does not provide 100% certainty that the boxes contain the agreed-upon goods. Due to the discontinuity between the real physical level and the information level, smart contracts have the same problems as normal escrow mechanisms.

Returning to the aspect of auditability, it can be argued that a distributed database with immutability through mutual supervision is useful. It is costly though because the necessary storage space increases multiplied by the number of participating firms due to the replication of the database and the data cannot be deleted for some time, as otherwise no audit would be possible. Indeed, the storage requirements and the inefficient database structure of an SC blockchain (*Linked List*) may be especially important due to the extraordinary complexity of supply chains, which grows exponentially with the number of value-adding levels. For example, a finished product could consist of 20 intermediate products that are produced by 40 different tier 1 suppliers. For their products, these 40 tier 1 suppliers could in turn, each use 10 intermediate products from 20 different tier 2 suppliers. The tier 2 suppliers in turn could each use 10 tier 3 suppliers. Although the finished product is made from only 20 intermediate products, a total of 40*20*10=8,000 companies could be involved in the supply chain. Indeed, the outlined supply chain is not overly complex. A typical car, for example, has about 10,000 tier 1 parts. Moreover, downstream processes and transports between companies further increase complexity. All these points of contact would have to produce information that fits together.

Therefore, the typical SC blockchain will probably be article specific and contain only those companies that were actually involved in the supply chain process of the respective article. However, even an article-specific supply chain can be very complex. Furthermore, the flood of data increases greatly when IoT technology is used [14]. The vision of real-time visibility can be achieved only by using telematic modules that constantly measure and transmit their TnT data (location, temperature, etc.) to a database. Thus, the CPU and storage requirements of an SC blockchain might be more costly than one might think. A compromise in this context could be to store only the hashes of data blocks in the shared blockchain and to store the actual data blocks only at the company where they were generated ([9], p. 256).

A tracking and tracing solution must not be too expensive. Otherwise, the return on investment becomes negative, and the project is set up to fail. This leads us back to the historically proposed solution of a data trustee ([8], p. 350), an independent, noncompetitive firm that acts like an escrow agent holding the participant's data under lock until an audit is necessary. This solution, however, has the disadvantage that the companies have to trust the *data trustee* to not change any of the stored data. Furthermore, the *data trustee* is a service provider, which makes the system more complex and increases transaction costs. Therefore, this solution is not ideal either.

Besides the issue of a costly IT system, history has shown that many companies are very hesitant to share their data. A popular vision often mentioned in connection with blockchains is that every customer can easily check the complete supply chain for a specific product. However, to make the complete supply chain of a product visible, every company involved would have to disclose their ingredients and suppliers. This is unrealistic, as data is increasingly considered one of the most valuable assets of a company. One solution would be to make the sharing of information mandatory, but a company would then have to expect that some suppliers would no longer be available and the prices of other suppliers would rise. This trade-off needs to be considered thoroughly. In this context, the *MediLedger* project offers an interesting form of traceability, where one can confirm that a drug has passed through certified companies but it is unknown who these companies were [9]. Nevertheless, in some situations, this information may be sufficient. The general reluctance of companies to share their data could change with evolving end-customer demands regarding transparency. This is, however, a topic largely independent of the technology used.

SC blockchain pilot projects are naturally limited in their scope. After all, they are used to provide a first proof of concept and not a final mature application. Nevertheless, to our knowledge, there is to date no SC blockchain that covers a reasonably complicated supply chain in its entirety. The existing pilot projects track either very simple products (e.g., mangos) or just

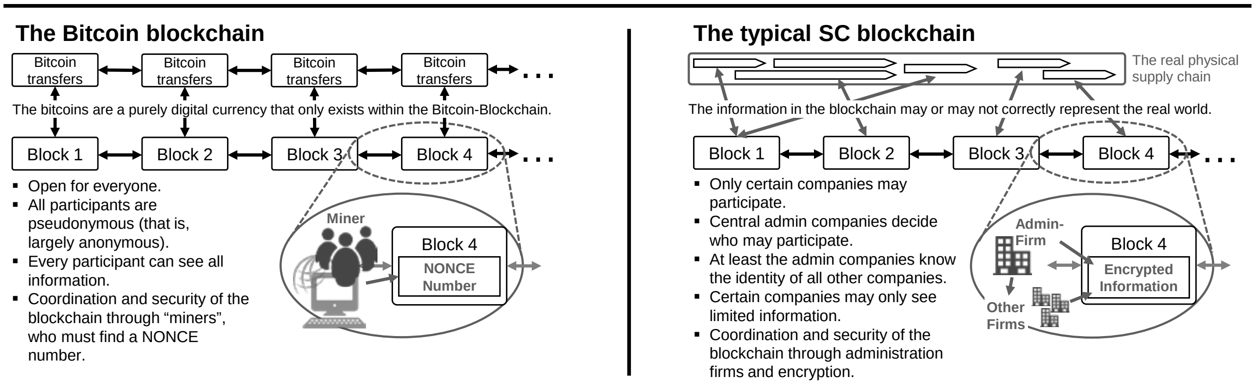

Figure 1. The differences between the Bitcoin blockchain and the typical supply chain blockchain

track trade and transport (e.g., sea freight/*Maersk*).

4. A survey of TnT solution providers

While there are some surveys that investigate the sentiment regarding the use of blockchains from a customer perspective (e.g., supply chain managers in [6]), to the best of our knowledge, there is no survey yet that examines the sentiment from the viewpoint of track-and-trace solution providers. In addition, such a survey can be helpful to better understand what problems exist when implementing and using track-and-trace software in practice. To identify the providers of TnT software solutions we opted for a broad search design using the normal *Google* search engine. Companies that only offered software for intracompany tracking and tracing (e.g., for warehouses) were excluded from the search. We were able to identify 218 companies (March 2020). Due to the broad search design and the number of results, we are confident that we have identified a representative portion of the TnT software market.

According to our market analysis (see Table 3), the vast majority of the companies did not yet seem to show much interest in blockchains. This market analysis is based on the company websites. It therefore contains only blockchain-based solutions that are communicated by the companies. As was to be expected, the 26 companies with some kind of blockchain solution can comparatively often be classified as either concerning provenance tracking or as having a broad/vague approach classified as end-to-end visibility. However, this is only a snapshot, and an outlook into the future is equally important.

We were able to survey experts from 21 different companies in the form of an online questionnaire mainly using 1–5 Likert scales. On average, the surveyed companies offered TnT software for 14 years (range: 2–35) and had 207 employees (range: 5–1950). As the 21 companies cover only approximately 10% of the identified market (# of companies), the following statistics can only be seen as an indication for the whole market. It is also important to note that the surveyed track-and-trace experts were not technical blockchain experts. Most of the experts stated that they have only solid knowledge about blockchains. Nevertheless, the experts have much knowledge about the general TnT market and customer requirements. Nearly half of the surveyed companies (~43%) offer some kind of blockchain product vs. 12% of the companies in the overall market (see Table 3). Our survey is therefore heavily biased towards solution providers that are open-minded with respect to blockchains.

Figure 2 shows the opinion of the experts regarding blockchains. Generally, the sentiment was rather positive. Almost all experts thought that a blockchain has its merits outside of TnT. The positive opinion was less pronounced for TnT in SCs but still rather positive. On average, the experts disagreed with our prediction that blockchains will not revolutionize TnT in SCs. When asked openly why the experts think that blockchains will revolutionize TnT in SCs, the most common answer can be summarized as: secure, distributed, immutable data archival.

Less positive is the success of existing blockchain solutions. Blockchain products are often less successful

Table 3. Market analysis of TnT providers

In which **area** do the 218 companies offer solutions?		
Logistics	Provenance	E2E visibility
64% (139)	23% (51)	13% (28)
How many have **exclusively** or **also** blockchain solutions and how many only **talk about it** (e.g., blog post)?		
Exclusively	Among others	Only talk about it
4% (9)	8% (17)	16% (35)
In which **area** do the companies with blockchain solutions (26) offer their solutions?		
Logistics	Provenance	E2E visibility
31% (8)	31% (8)	38% (10)

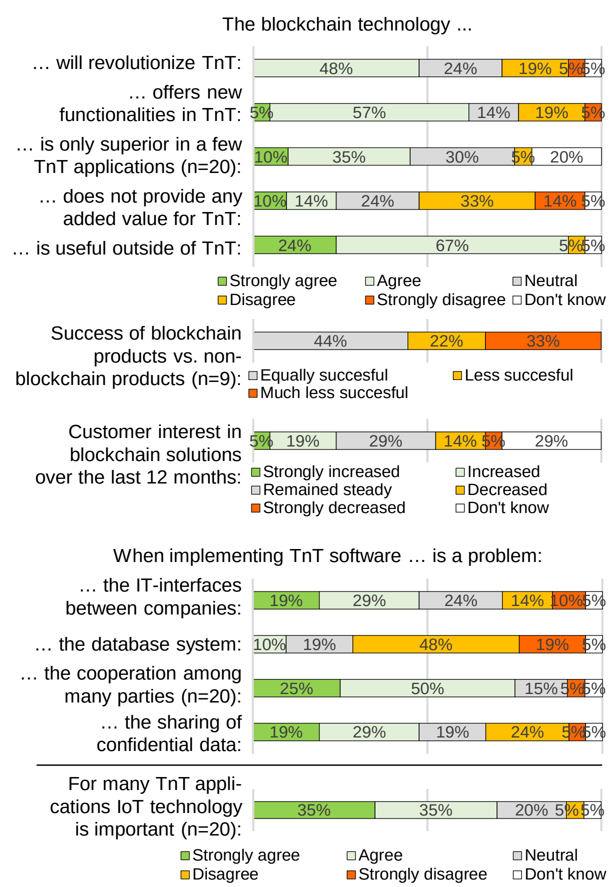

Figure 2. Selected survey results

than products without a blockchain (see Figure 2). In addition, 48% of the experts reported that customer interest in blockchain solutions has remained the same or decreased compared to only 24% who reported increasing demand. However, almost all surveyed companies (18/21) want to offer blockchain solutions in the future, albeit only some (10) or very few (7) products, indicating that the planned blockchain solutions are intended to complement the existing product portfolio. Table 4 shows the agreement of the experts on reasons why they plan future TnT blockchain solutions or not. These answers reveal a more mixed sentiment.

The vast majority of the experts stated that the database technology in general is not a problem when implementing TnT software (see Figure 2). Moreover, the experts consider a central database to be the most useful (Ø2.19 agreement, n=16) and a distributed database the least useful (Ø3.69, n=13) architecture. Since the blockchain is a distributed database technology, it can therefore be questioned how much benefit it can generate in practice. Instead, other problems, which probably cannot be solved by blockchains, seem to be more important in practice. In particular, cooperation between many parties is a common problem according to the surveyed experts. Some parties in the supply chain may question what their benefits are, especially because sensitive data might have to be shared and expensive IT interfaces must be implemented. It is questionable whether blockchains can help with this problem.

Furthermore, many experts (11/19) stated that customers often want a TnT solution that only they can access. Only 4 experts stated that customers often want a TnT solution that is accessible to multiple companies. This is in contrast to a blockchain solution. A blockchain is useful only if the TnT solution is to be accessible to multiple companies. A solution accessible to only one company can be implemented more easily with different technologies.

Customers often want to trace the transport route of shipments (Ø2.15, n=20) or to identify the manufacturer of a product (Ø2.42, n=19). Less often, customers want to make automatic payments or transfers of ownership based on track-and-trace data (Ø3.42, n=19). This suggests that smart contracts may not be in great demand. However, this is merely a snapshot of the current demand, which can change over time.

Table 4. Top reasons for/against blockchain

Reasons **for** future TnT blockchain solutions:
Expected sales growth (Ø2.14, n=14)
Expected increase in reputation (Ø2.21, n=14)
Expected better task accomplishment (Ø2.31, n=16)
Reasons **against** future TnT blockchain solutions:
Customers do not demand it (Ø1.89, n=9)
Does not provide competitive edge (Ø2.00, n=10)
It is technically unnecessary (Ø2.11, n=9)

Overall, the surveyed experts appeared to have a rather positive attitude towards blockchains but lacked technological knowledge. The results of the survey suggest that the experts equated the term “blockchain” with the term “distributed (immutable) ledger”. From a scientific point of view, they are not the same, but in practice, it may not matter. Practitioners are interested in certain features of a TnT solution, and the experts in this study noted the advantages of secure, distributed, immutable data archival. How these features are technically ensured is the task of IT staff. However, the rather small sample size of course limits the general validity of the aforementioned results. In addition to surveying more companies, it seems necessary and expedient to specifically interview IT staff.

5. Conclusion

Due to its immutability and distributed nature, a blockchain seems to support tracking and tracing in SCs and thus improve supply chain management. However, it can be stated that a private permissioned blockchain, which is often used for TnT in SCs, offers no clear advantage over existing and established technologies. Public permissionless blockchains offer new functionalities, but they are most useful if the use case requires that all participants are pseudonymous, new participants can join at will and each participant can read/write and verify data. However, such use cases are probably rare in the context of tracking and tracing and in supply chain management more generally. Nevertheless, we are still in the relatively early stages of researching the blockchain and its possible applications [22]. Perhaps the blockchain will not revolutionize the existing tracking and tracing efforts but instead can help to make entirely new systems possible.

However, blockchains currently do not seem to be the Holy Grail for TnT in SCs. An often-touted advantage of blockchains is that they represent a single point of truth. This is, however, not necessarily true in the context of a supply chain. In an SC blockchain, there are two levels: the digital information level, which exists in the SC blockchain, and the physical supply chain level, which exists in the real world. These two levels do not necessarily have to match, because the participants can lie and sensors may be faulty or manipulated.

There are also more fundamental problems in the context of tracking and tracing. Regardless of the technology used, the SC parties must be willing to collect and share track-and-trace data. Otherwise, transparency and traceability in supply chains are not possible. However, costs and competitive reasoning often make this unattractive. Nevertheless, it can also be positive if old problems are re-examined, not with better technology but with new technology and renewed enthusiasm. According to our survey, TnT software providers seem willing to give blockchains a chance. Moreover, some of the experts disagree with us and think that blockchains will probably revolutionize the TnT market. However, it is questionable whether this enthusiasm is sufficient to overcome the fundamental economic hurdles.

A great opportunity exists in the field of IoT technology. If sensors and telematics modules can be produced very cheaply, they could be used much more often, and the problem that the real world could not match the digitally recorded world would be at least somewhat mitigated. However, it is still unlikely that a 100% match is achieved, and in addition there is the problem of who controls these sensors, labels and telematics modules ([23], p. 53). Nevertheless, the additional data would benefit tracking and tracing as a whole regardless of the database architecture.

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